Modelling of forming

using Metafor – a large strains FE software

Scope

Introduction

University of Liège – LTAS-MN²L

- ***ULg*** = University of Liège (8 faculties – 400 professors – 2000 researchers – 17000 students / 20% foreigners)
- ***LTAS*** = Laboratoire des Techniques Aéronautiques & Spatiales (Aerospace Laboratory) – includes 8 laboratories ~ 60 engineers
- ***MN²L*** = Mécanique Numérique Non Linéaire (Non-Linear Mechanics)

Non-Linear Mechanics laboratory

General research interests

- Process simulation including large strains (Prof. Ponthot)
    - Material forming
    - Crash & impact problems
    - Tire Mechanics
    - Biomechanics

J.-P. Ponthot

Main Industrial partners

GDTech / Samtech (*)	(Engineering services)
ArcelorMittal (*)	(Steel maker)
SNECMA	(Aero engines manufacturer)
TECHSPACE-AERO (*)	(Aero engines manufacturer)
SABCA	(Ariane 5 components)
SONACA	(Airbus components)
GOOD-YEAR	(Tire manufacturer)

(*) owns a Metafor license

Metafor

Our home-made software : Metafor

Our “experimental” facilities at LTAS-MN²L

- None, except PCs, servers, compilers, …
- We focus on:
    - New algorithms development & implementation
    - Engineering software design

What is Metafor?

A Non-linear finite element software mainly used for the simulation of Metal Forming processes.

History of Metafor

1992	Metafor – Fortran77 (Ponthot’s thesis).
1992-1998	Awkward integration of some PhD theses.
1998	Unmanageable situation – new routines added using C.
2000	Oofelie was discovered – complete rewriting using C++/python.
2000-2008	All developments integrated inside one software : Metafor.

Our home-made software : Metafor

Our aims

- Never loose the previous developments (PhDs, research projects,…).
- To gather the researchers together on a unique software platform.
- Full control of the source code.

“Basic” FEM Toolkit

Our tools

C++/python	: common language
SVN	: 1-2 releases / week
Tests suite	: >1200 tests on 01-09-2008
Doxygen	: programmer’s documentation
Web site	: user’s documentation (in French)
Programming rules	: (simplified) “Ellemtel” coding rules

Current Metafor team

R. Boman

Dr PP. Jeunechamps

Dr O. Karaseva

R. Koeune

Prof. L. Noels

V. d'Otreppe

M. Mengoni

L. Papeleux

Prof. E. Fancello

Dr G. Deliége

Non-Linear FEM

Main equations to be solved

$$\boxed{\begin{array}{ll} \rho\, \ddot{x}_i = \dfrac{\partial \sigma_{ij}}{\partial x_j} + \rho\, b_i & on\; V(t) \\ \sigma_{ij}\, n_j = t_i & on\; S(t) \end{array}}$$

(Momentum balance)

$\longrightarrow$ PVW

$$\delta M + \delta W_{\text{int}} = \delta W_{\text{ext}}$$

(Weak form)

$\longrightarrow$ Spatial Discretization (FEM)

$$\underbrace{\mathbf{M}\,\ddot{\mathbf{x}}}_{\text{Inertia forces}} + \underbrace{\mathbf{F}_{\text{int}}(\mathbf{x})}_{\substack{\text{Internal forces}\\ \text{(const. law)}}} = \underbrace{\mathbf{F}_{\text{ext}}(\mathbf{x})}_{\substack{\text{External forces}\\ \text{(contact, ext. loads, …)}}}$$

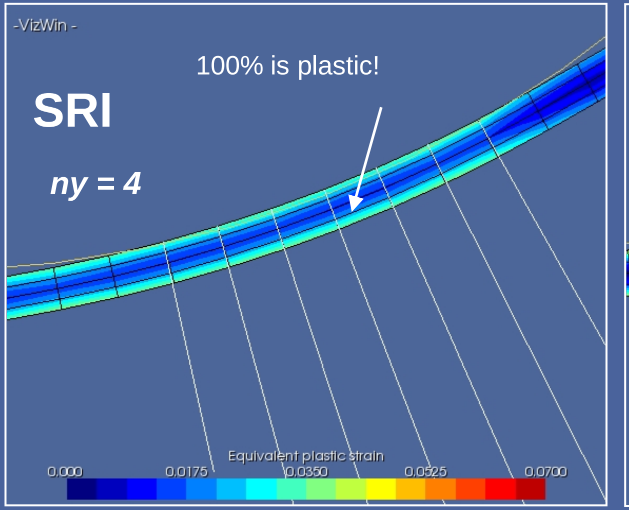
$\longrightarrow$ Time Integration

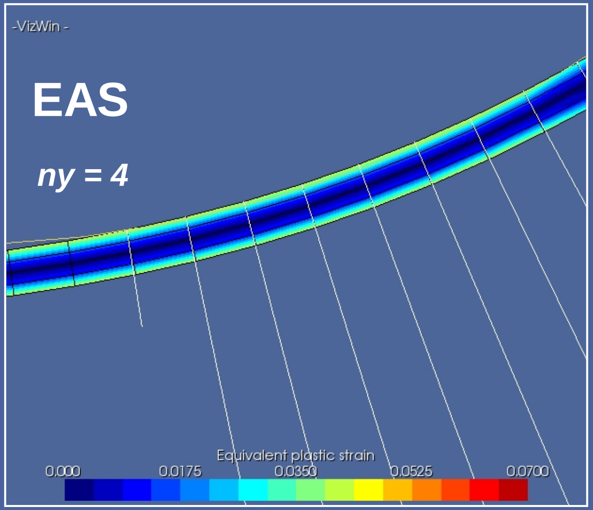
Incremental procedure (time steps) using
- either explicit schemes
- or implicit schemes (Newton-Raphson iterations)

Highly non-linear: large displacements, contact and friction, material behaviour, thermal coupling, etc

Large strains elements – SRI & EAS elements

- SRI: Selective Reduced Integration : common large deformation finite element (1 GP for p / 4 GP for dev. stresses)
- EAS: Enhanced Assumed Strain : avoids SRI shear / volumetric locking





Numerical applications

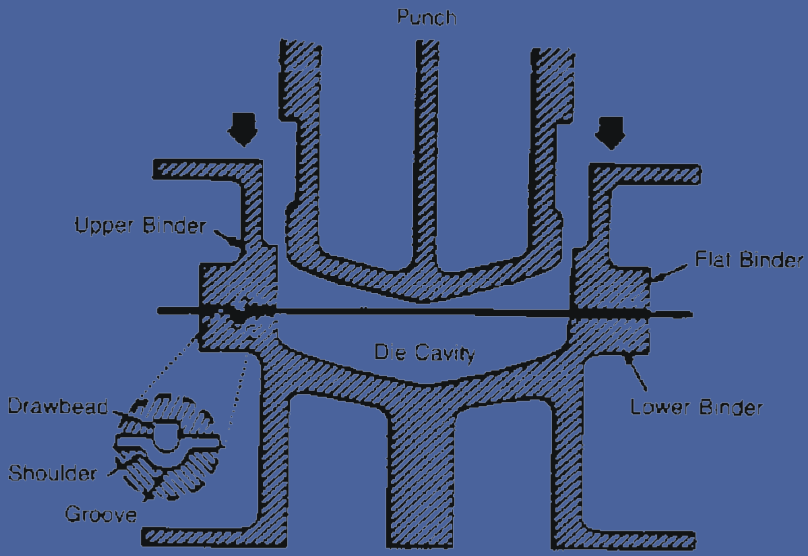
1. Contact
2. Material laws and related algorithms
3. ALE formalism

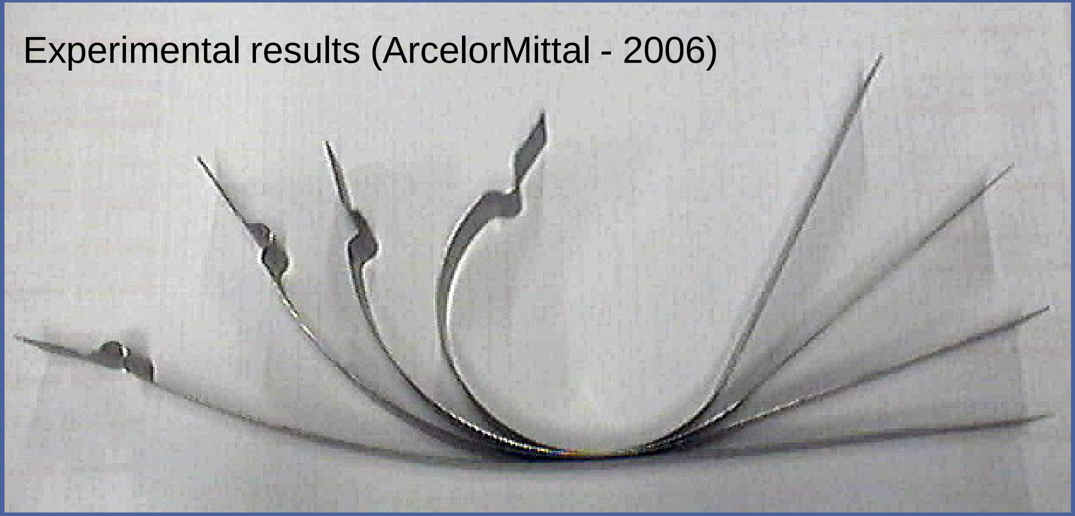
Contact

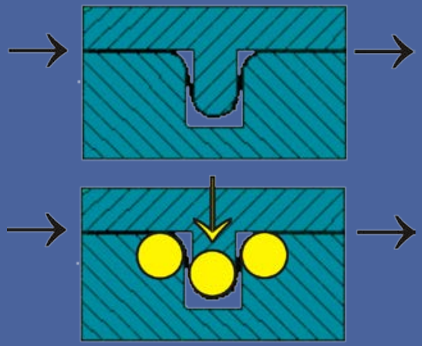
1. Drawbead (Nine’s test)
2. Deep drawing (S-Rail)
3. Tube Hydroforming
4. Roller levelling (3D)

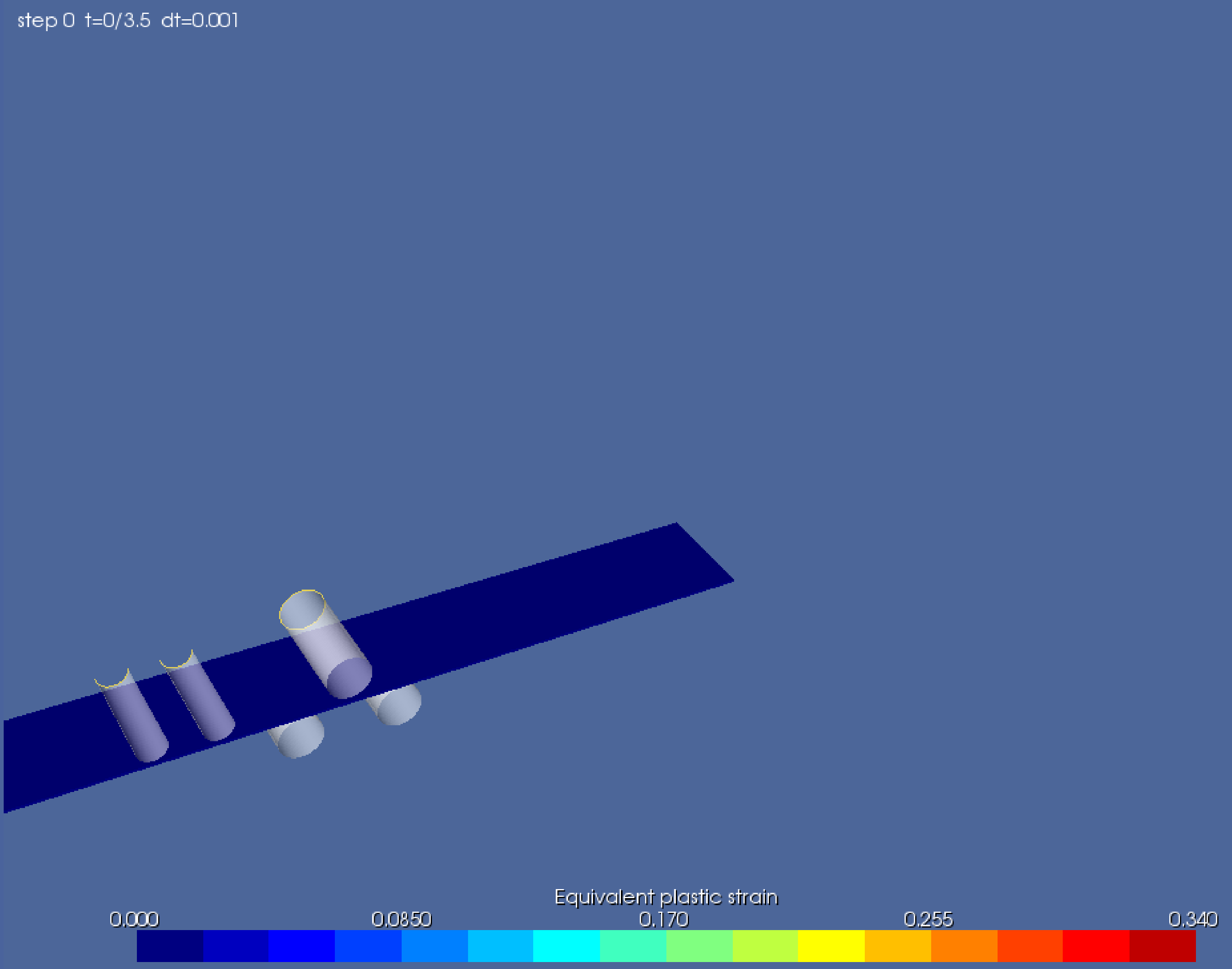
Drawbead simulator

- Numerical simulation of an experimental drawbead device (used by H.D. Nine – General Motors - 1978)
- Drawing and clamping forces are studied.
- Frictional component can be avoided if the rollers are free to rotate.
- Springback radius can be estimated and compared to experimental results




Experimental results (ArcelorMittal - 2006)

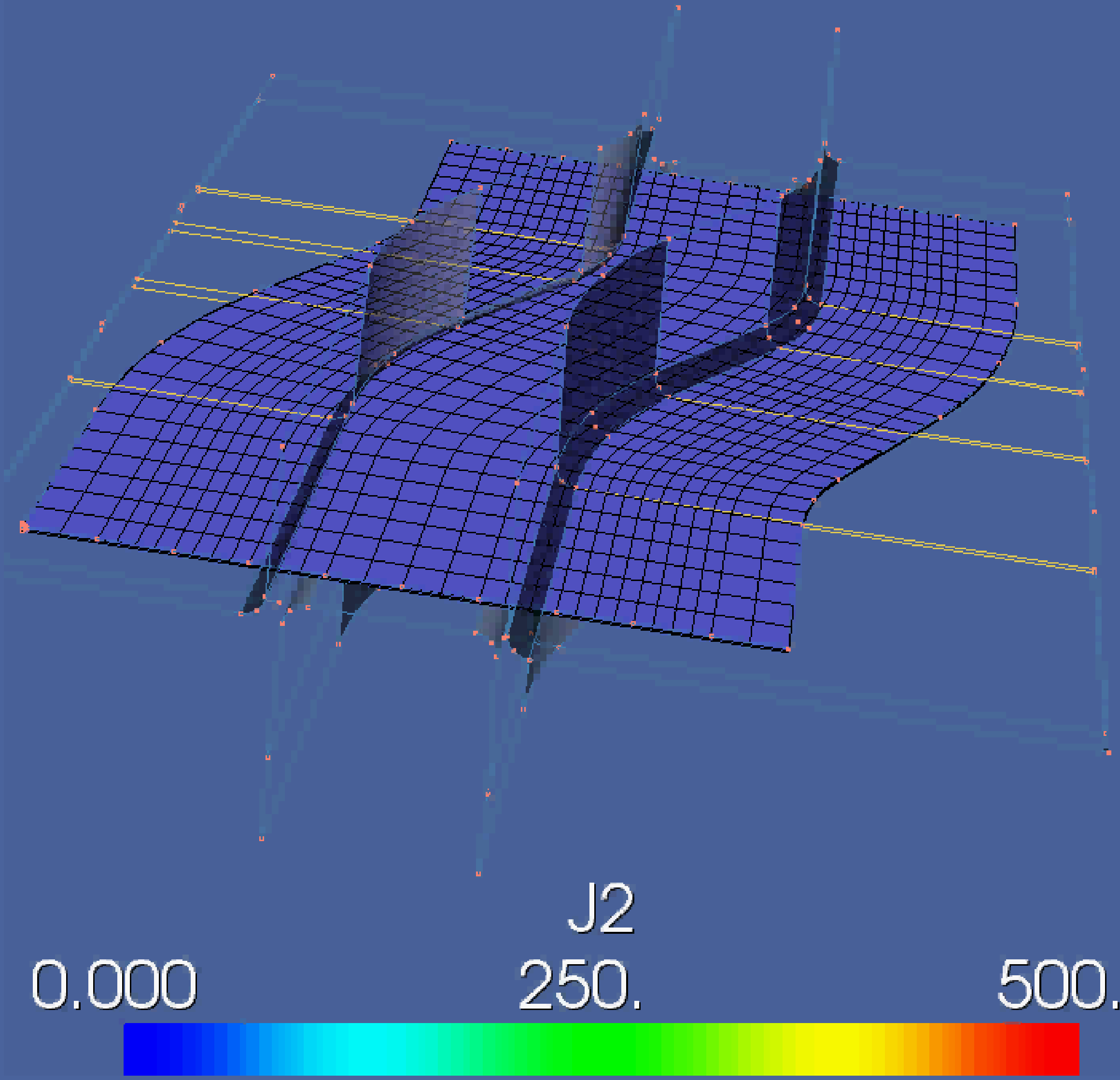



step 0 t=0/3.5 dt=0.001
Equivalent plastic strain
0.000
0.0850
0.170
0.255
0.340

S-Rail benchmark

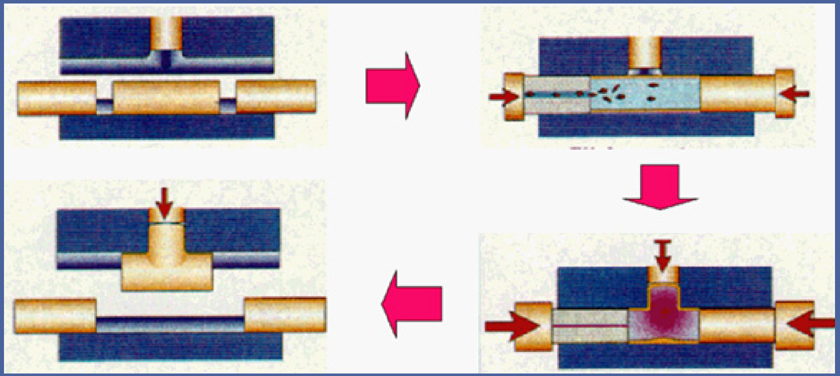
(Numisheet ’96)

- Deep drawing of an "S-shaped" rail.
- The die and the punch are rigid.
- Friction is taken into account between the tools and the blank.
- Springback is computed removing the tools and using an implicit scheme.

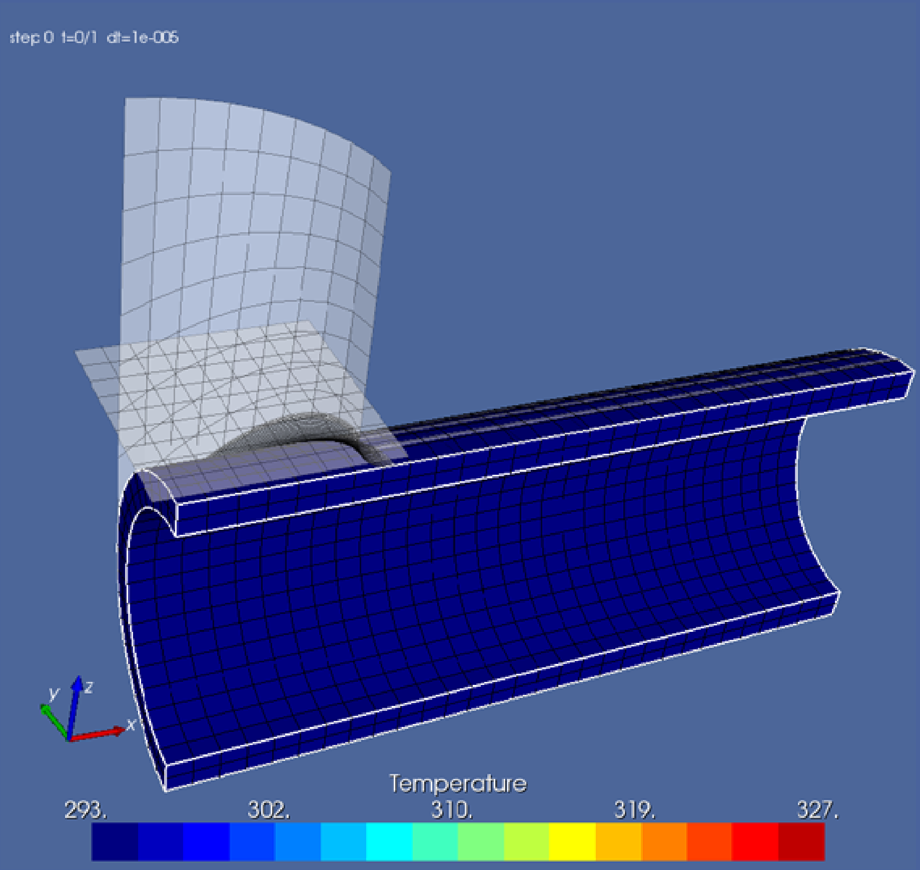


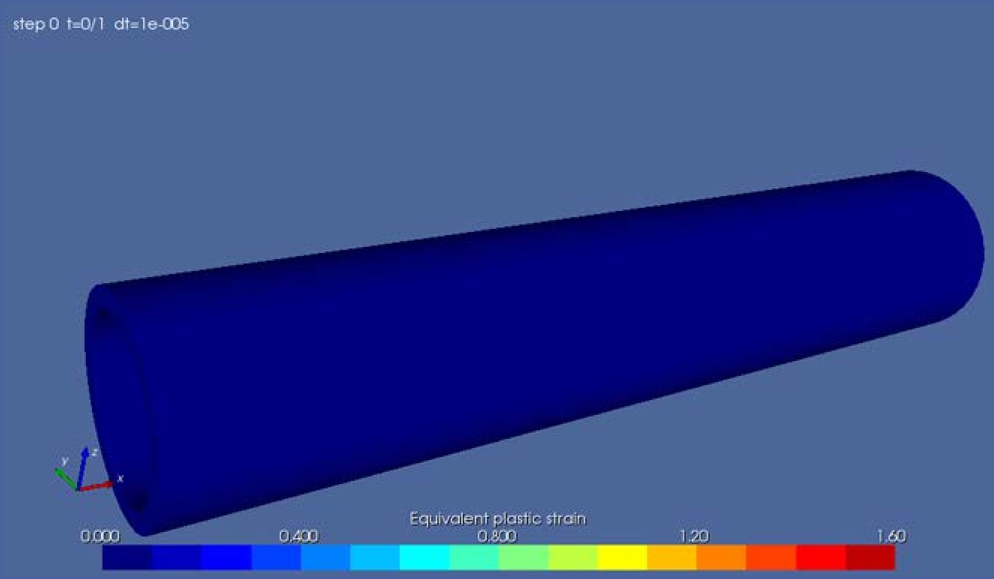
Hydroforming of a tube

- Thermomechanical hydroforming of a tube.
- Material with thermo-elastoplastic behavior.
- The exact geometry of the die has been imported from CATIA (including Nurbs surfaces).

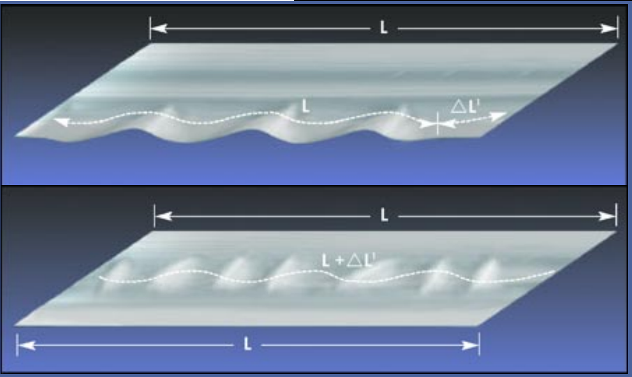


Hydroforming of a tube

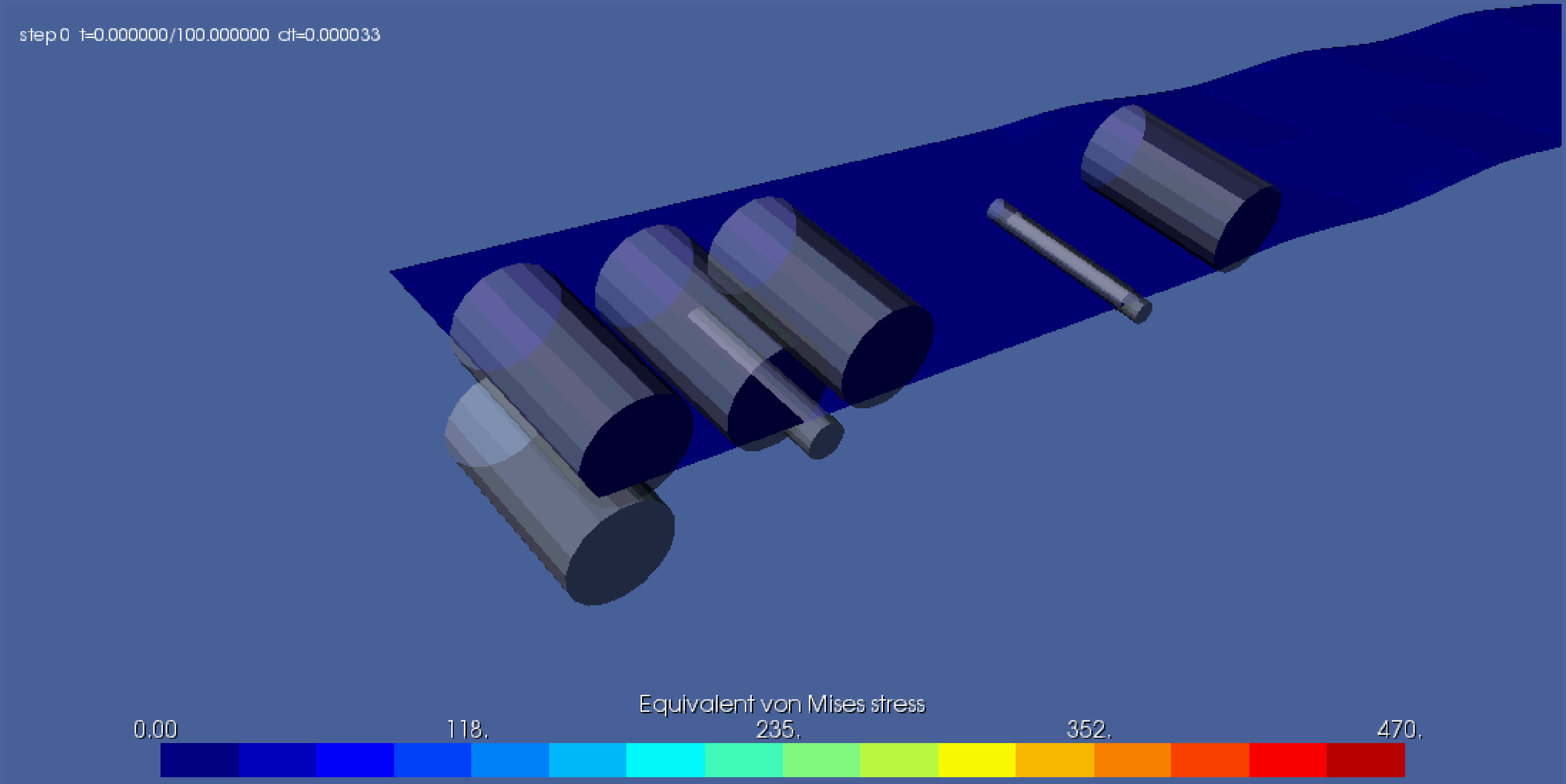




Roller levelling

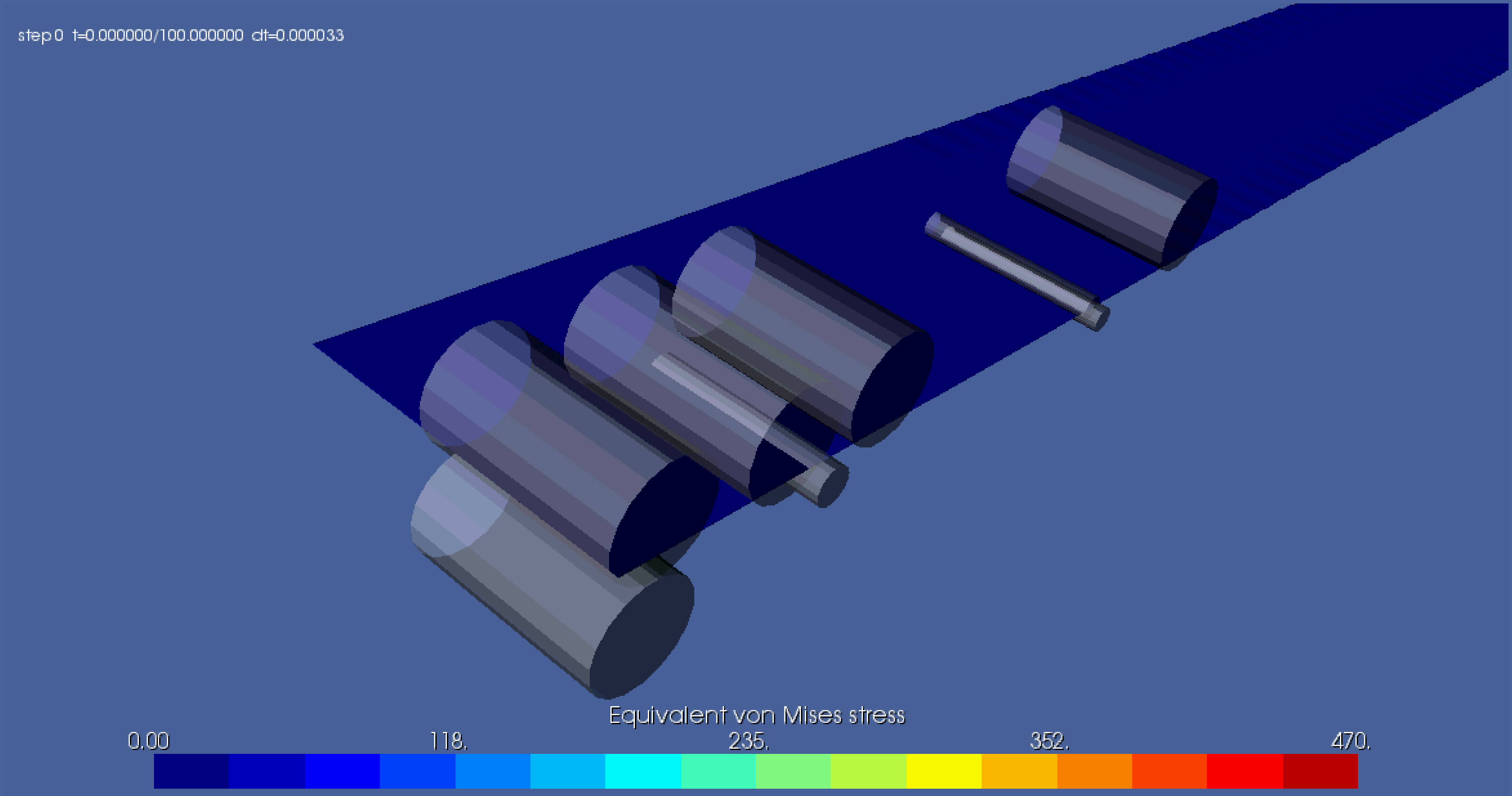


- Shape defects (edge waves) reduced through a set of rolls – centre buckle could be considered too.
- Geometry designed using python interpreted curves.



Roller levelling

- Edge waves : smaller wavelength

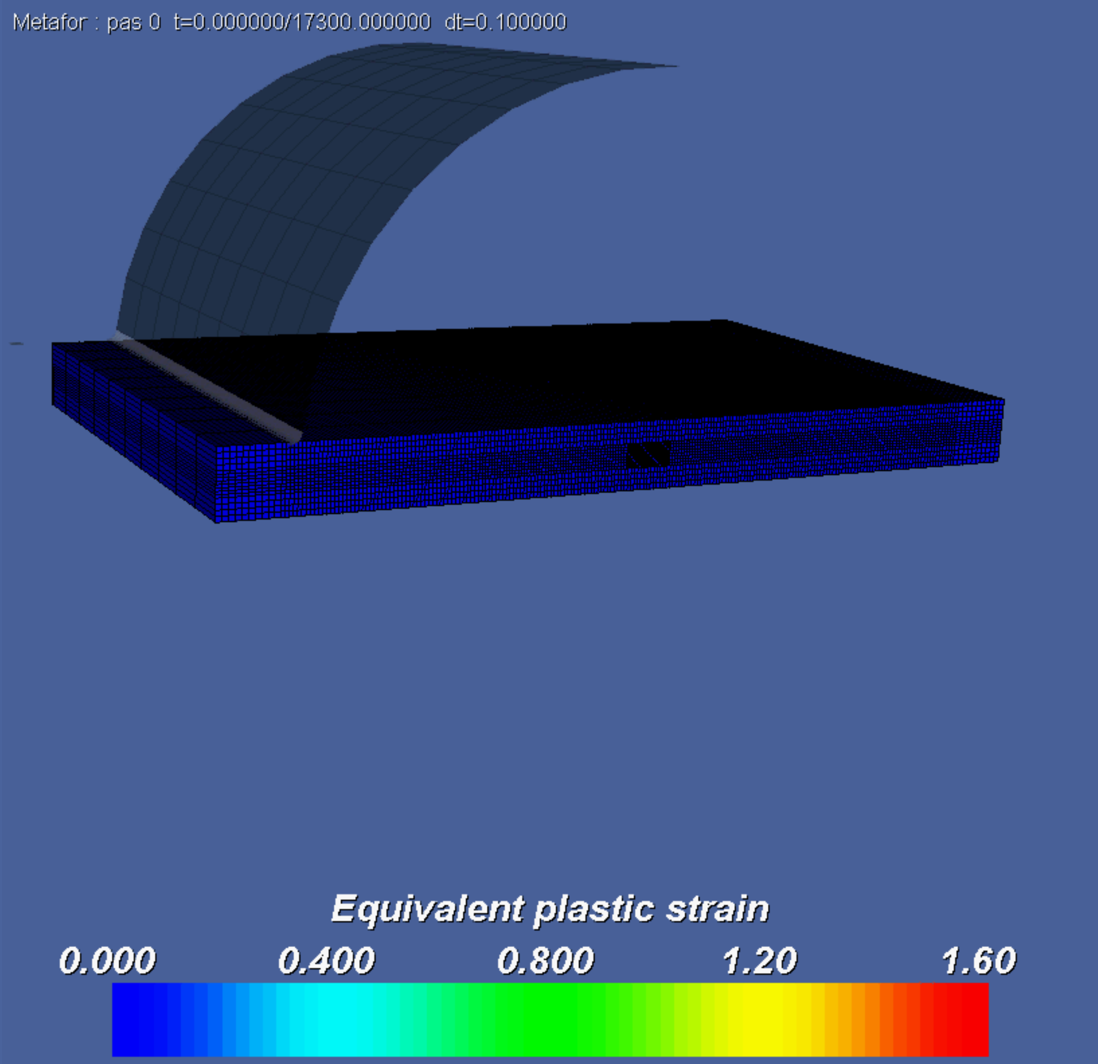


Material laws

1. Superplastic forming (tee)
2. Propagation of crack
3. Fast tensile test with damage and fracture
4. Orthodontics

Superplastic forming

- Superplasticity is a state in which a material is deformed well beyond its usual breaking point (high T, low strain rates).
- Multisheet superplastic forming of a self-stiffened titanium structure (Sonaca).
- Optimal pressure cycle is computed in order to stay below a given plastic strain rate.

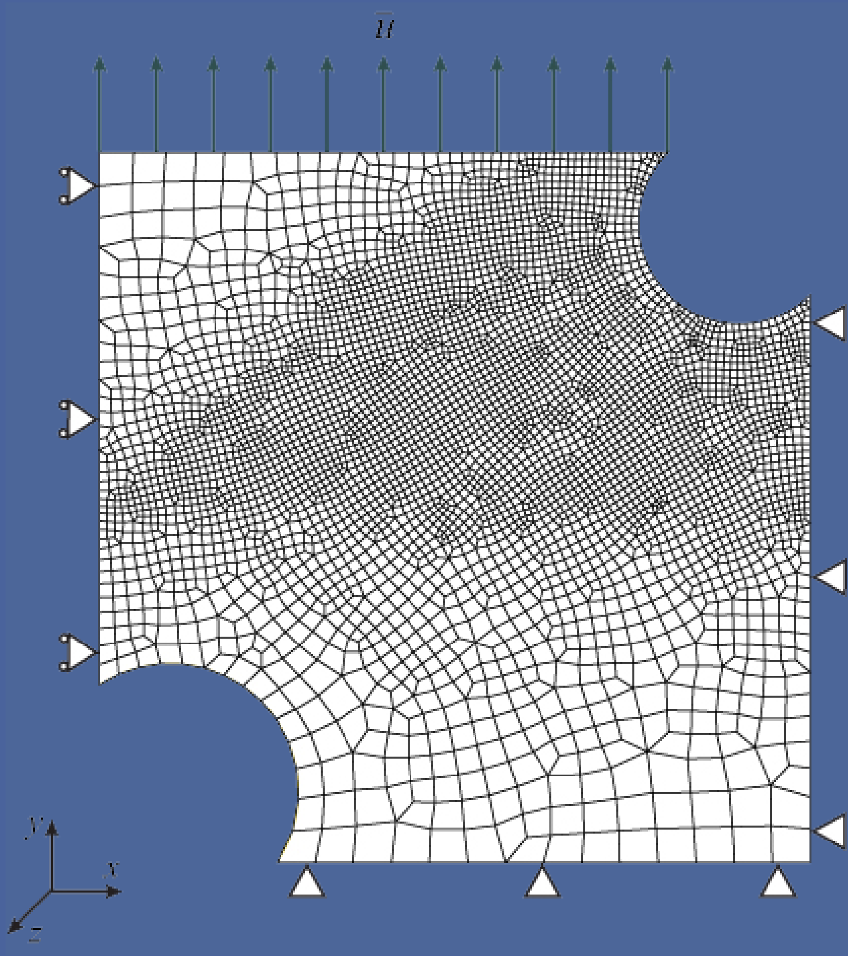


Ductile fracture – erosion method

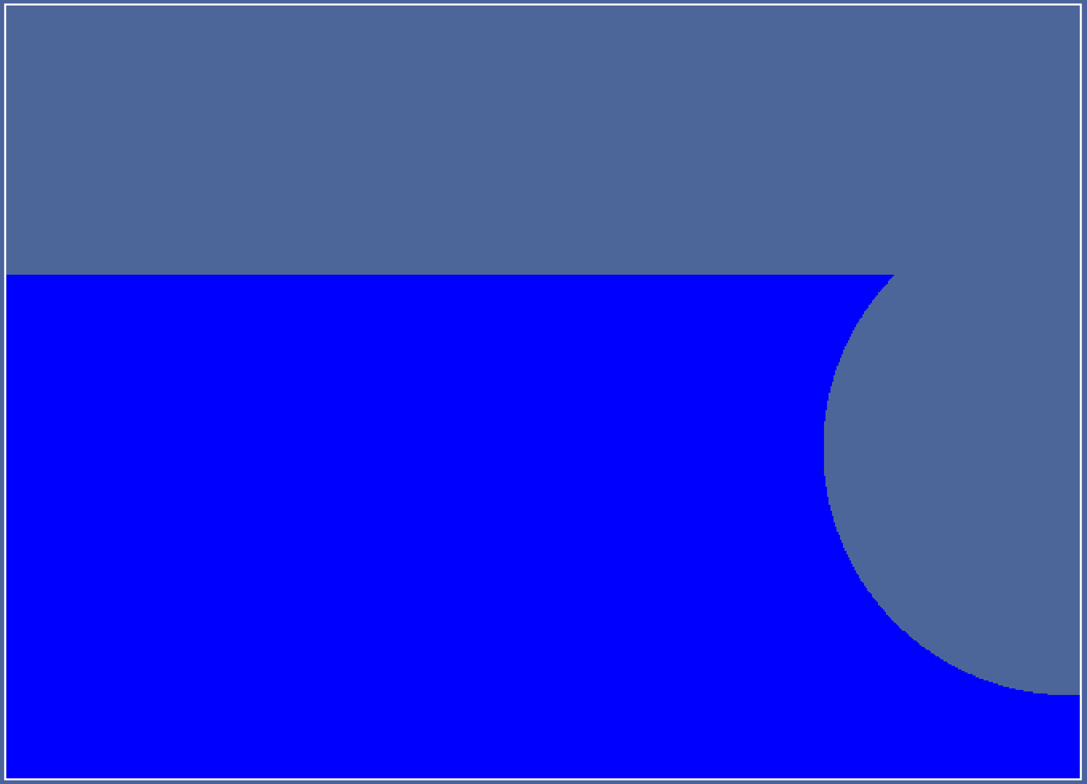
- Quasi-static traction test of double notched specimen.
- Meshes from 4500 to 314000 2D elements
- Erosion method to model material fracture
- Goijaerts fracture criterion (no damage):

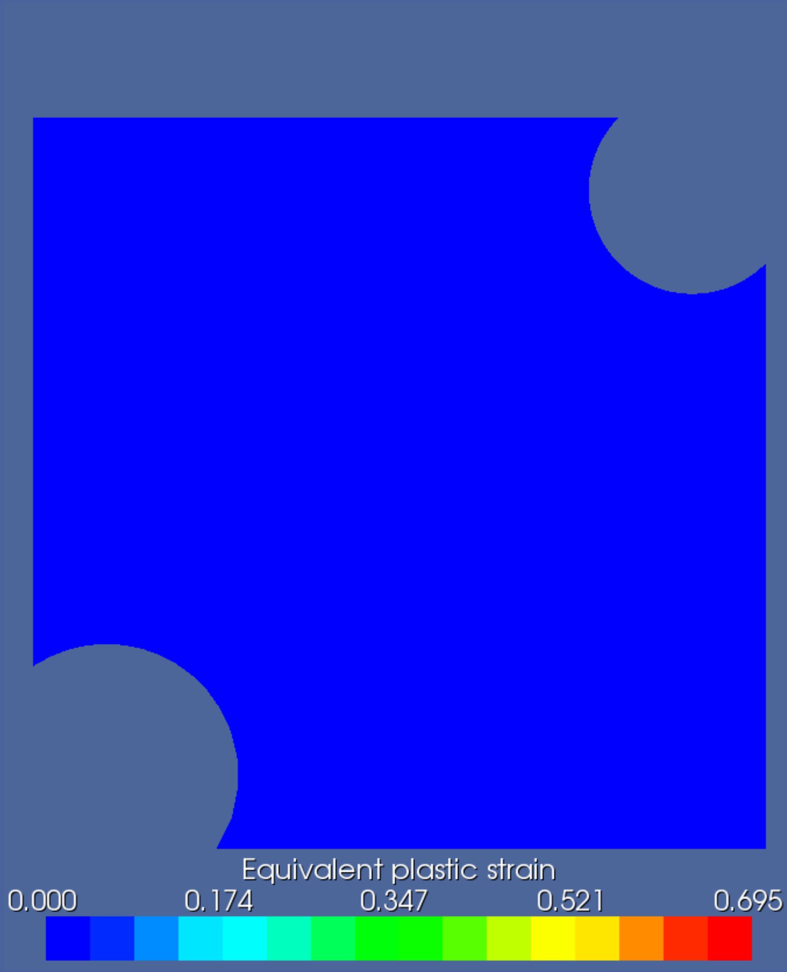
$$\int_0^{\bar{\varepsilon}_f^{pl}} \frac{1}{C}\left\langle 1+A\frac{p}{\sigma_{eq}}\right\rangle d\bar{\varepsilon}^{pl}=1$$

- Elements that reach this critical value are simply removed from the mesh.
- Mass loss and mesh dependency are studied.



Propagation of a crack





Ductile damage

Two main schools for irreversible degradation of material properties:

- *Gurson's theory* based on the void volume fraction ("porous metal plasticity" in Abaqus)

  => modified yield criterion: $f = \overline{\sigma} - w(D, p)\,\sigma_{yield} - \sigma_{damage} = 0$

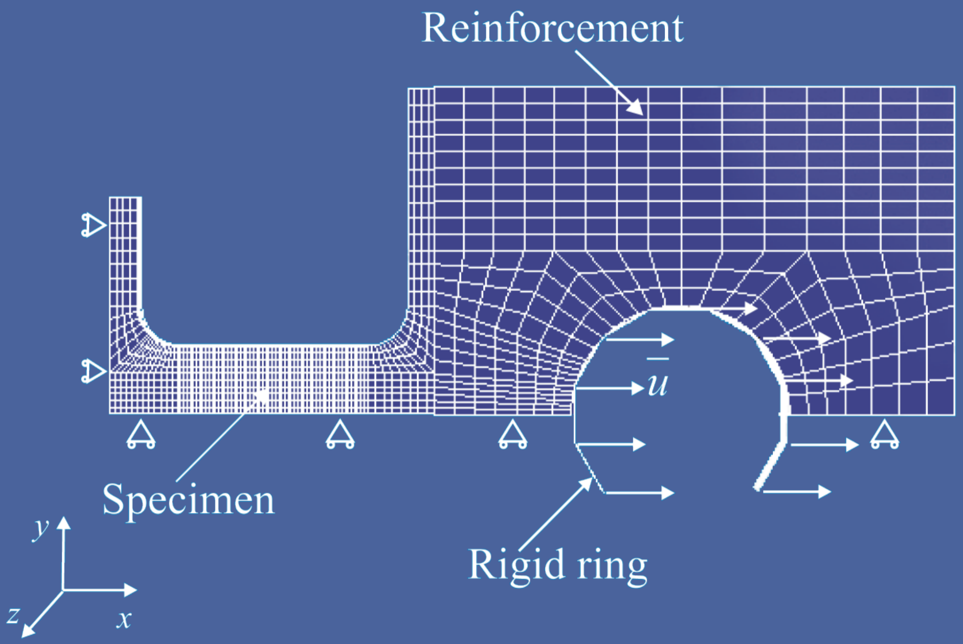
- *Lemaitre's thermodynamic continuum damage mechanics*

  => Plasticity is solved using the effective stress $\tilde{\sigma} = \dfrac{\sigma}{1-D}$ (*D*=isotropic damage)

Advantages of Lemaitre's theory:

- Existence of damage models for impact problems
- More flexible models
- Gurson's theory not easy to extend to dynamic effects
- Extended to large strains and thermomechanical coupling
- Any damage law can be used with any constitutive model

Fast tensile test with damage and fracture

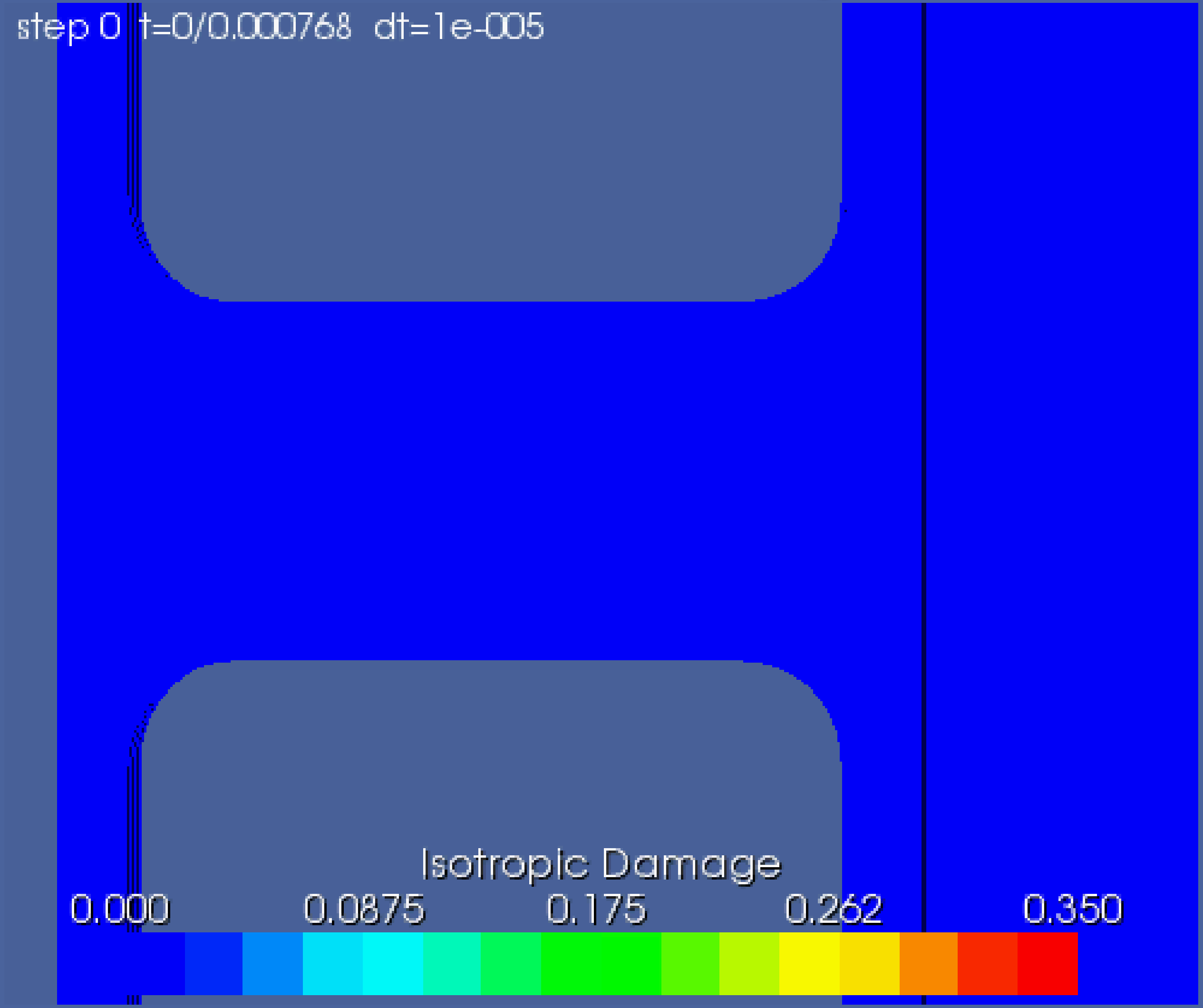


Johnson Cook's visco-plastic constitutive law:

$$\sigma_{crit} = \left(A + B\left(\bar{\varepsilon}^{pl}\right)^{n}\right)\left(1 + C\ln\frac{\dot{\bar{\varepsilon}}^{pl}}{\dot{\bar{\varepsilon}}_{0}}\right)\left(1-\left(\frac{T-T_{room}}{T_{melt}-T_{room}}\right)^{m}\right)$$

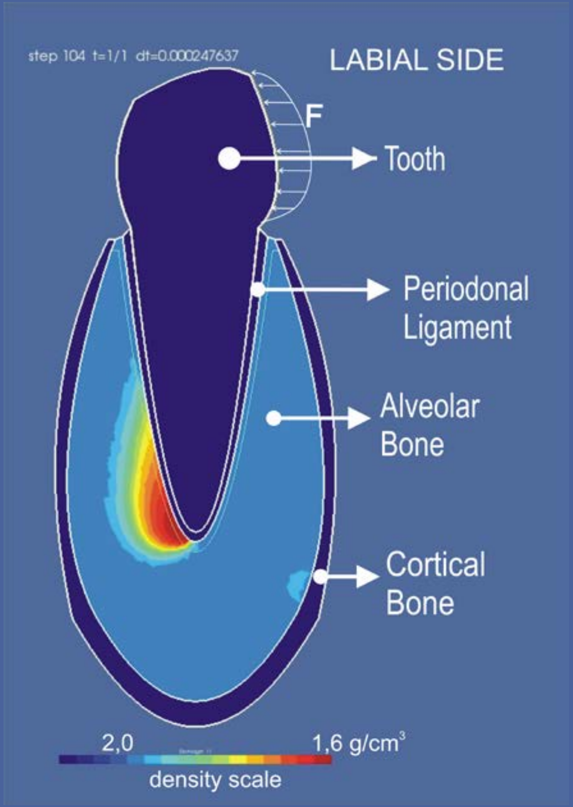
- 3D Simulation of a fast tensile test.
- Material: high strength steels (TRIP and dual phase)
- Thermomechanical implicit algorithm.
- Material model with dynamic material laws.
- Damage of material modelled with continuum damage mechanics (Lemaître)
- Erosion method to model propagation of fracture.
- In collaboration with Prof. Salima Bouvier (Laboratoire des Propriétés Mécaniques et Thermodynamiques des Matériaux - Paris)

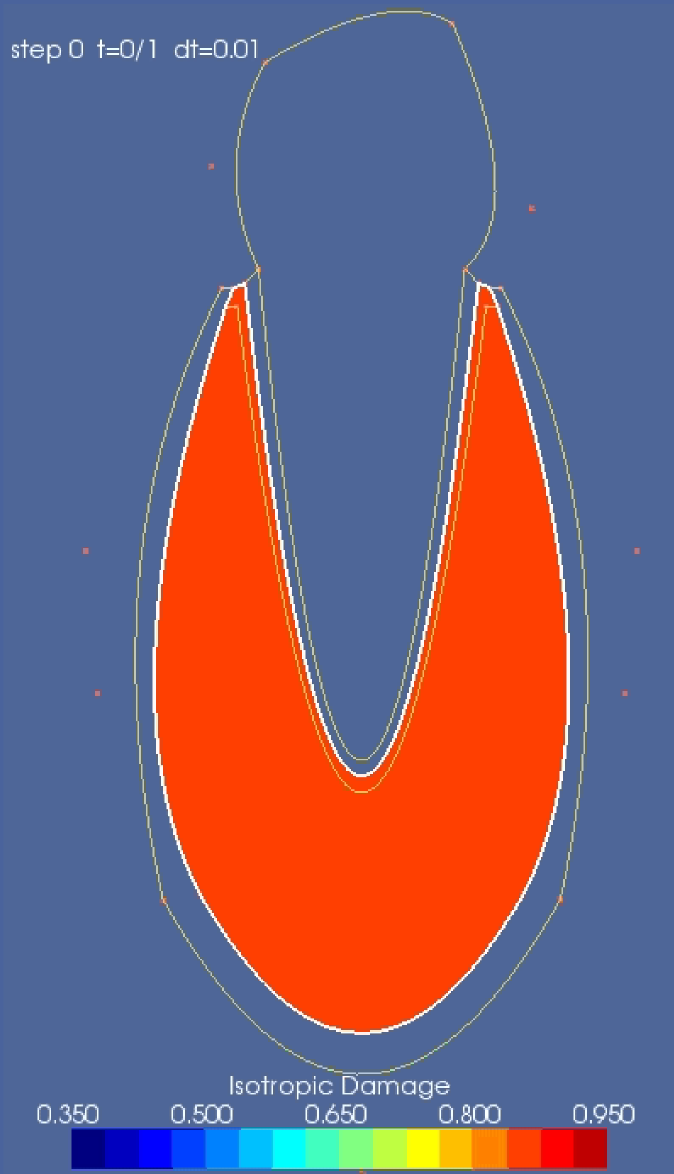
Fast tensile test with damage and fracture



Tooth Model

- Orthodontics – alveolar bone remodelling
- Remodelling = bone density variation according to biomechanical stimulus.
- Case of alveolar bone surrounding teeth



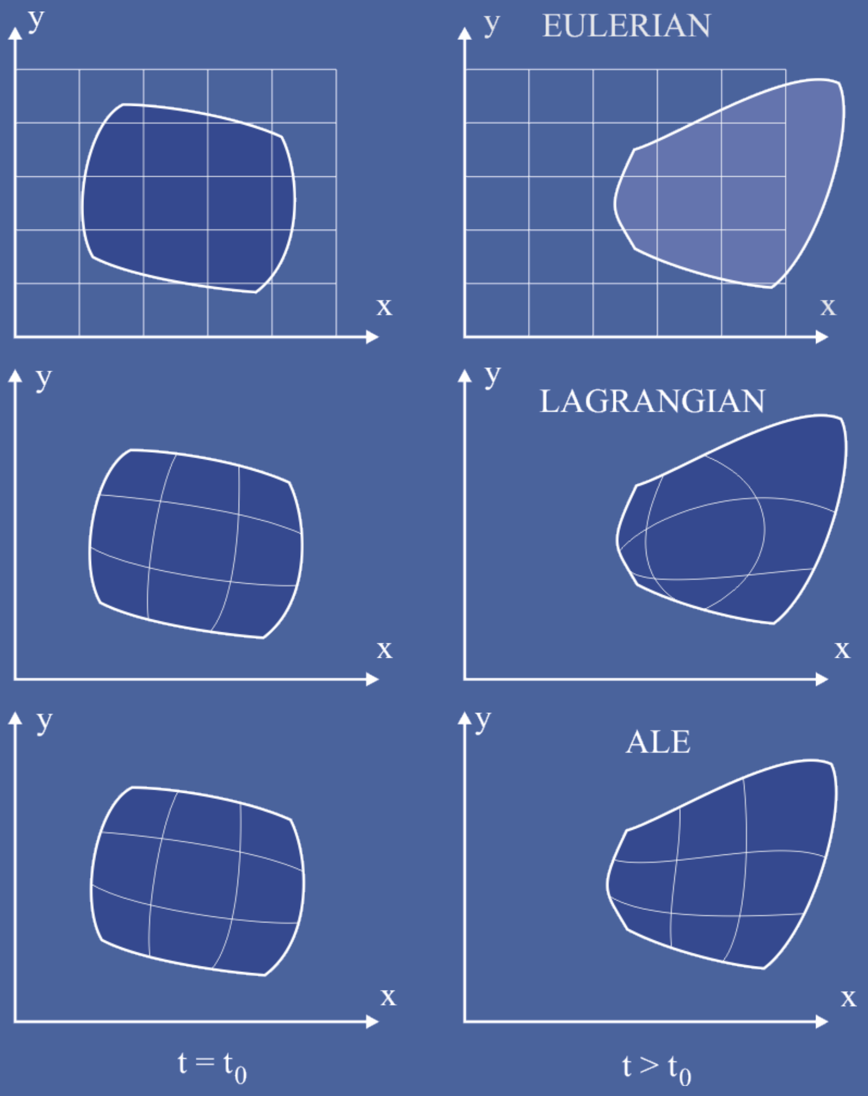


- Use of damage as a measure of bone density
- Continuum damage model with specific damage variation law

ALE formalism

1. Extrusion
2. Machining
3. Rolling
4. Roll forming

ALE formalism in a few words



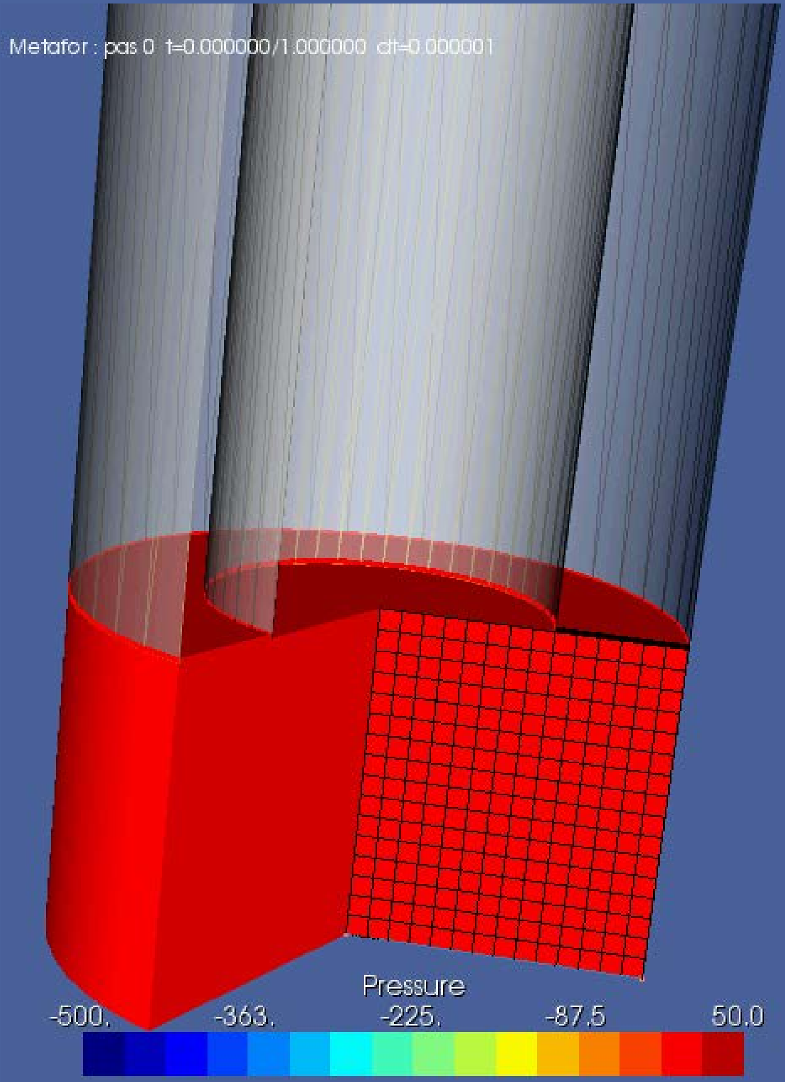
EULERIAN FORMALISM

- ✓ Undistorted mesh
- ✓ Ideal for stationary processes
- ✗ Free boundaries are difficult to follow

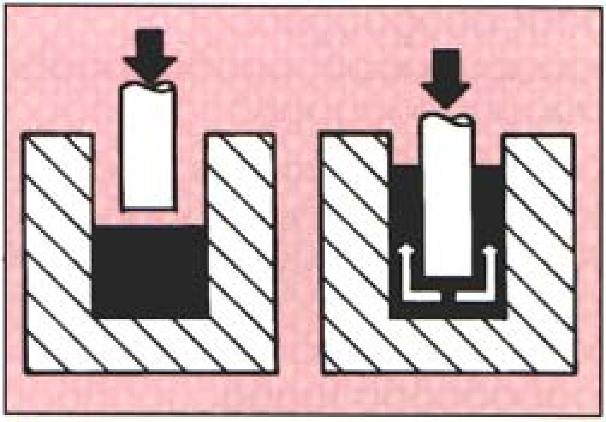
LAGRANGIAN FORMALISM

- ✓ Free boundaries are computed automatically
- ✓ History dependant materials are easier to handle
- ✗ The mesh can be rapidly distorted
- ✗ Large amount of finite elements are needed for the simulation of stationary processes

Backward extrusion using ALE

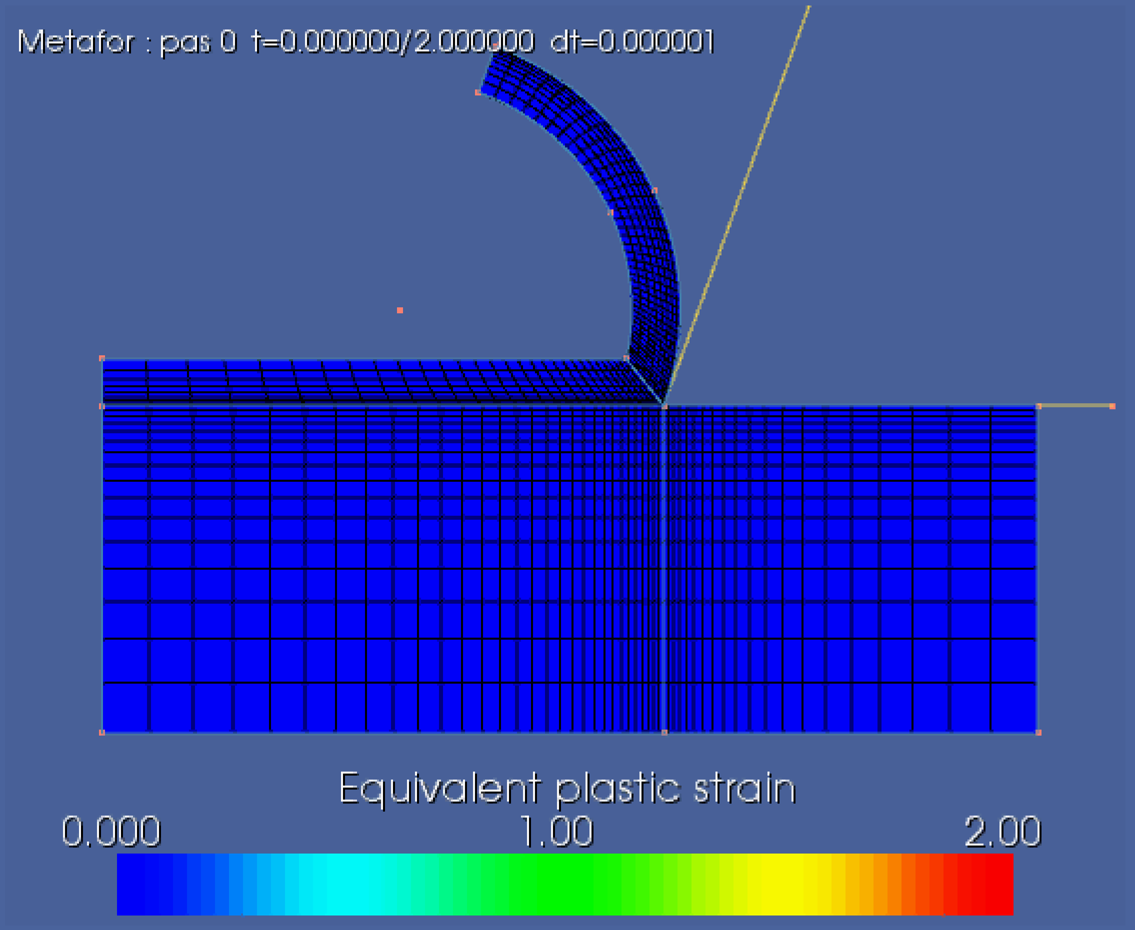


- A cylindrical piece of metal is pushed through a rigid tool.
- A very thin mesh is placed where the solid is supposed to go out.
- During the process, this flat mesh grows due to the convection and the main mesh shrinks.
- The shape of the mesh remains good and no remeshing is needed.

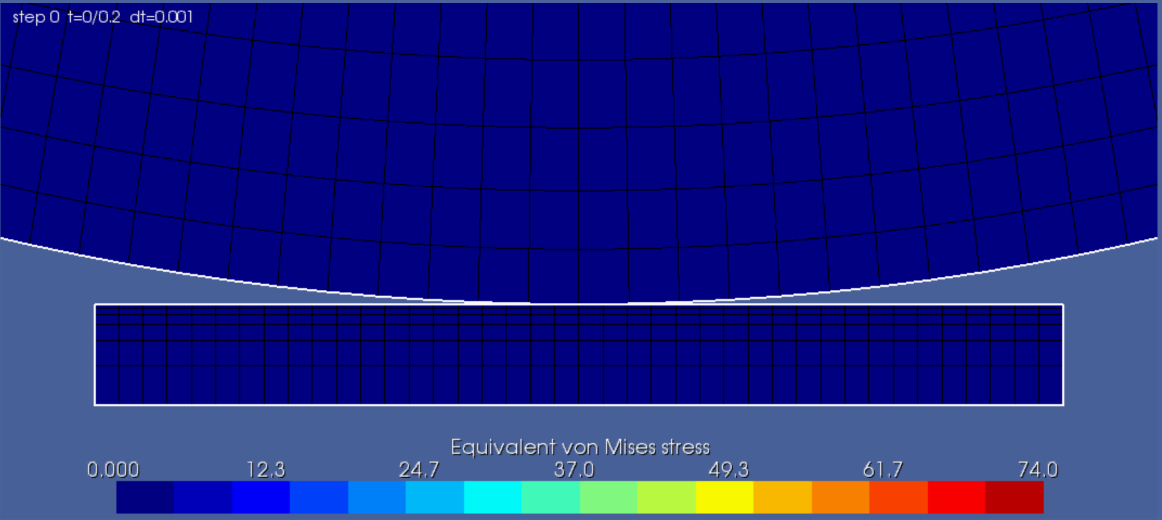


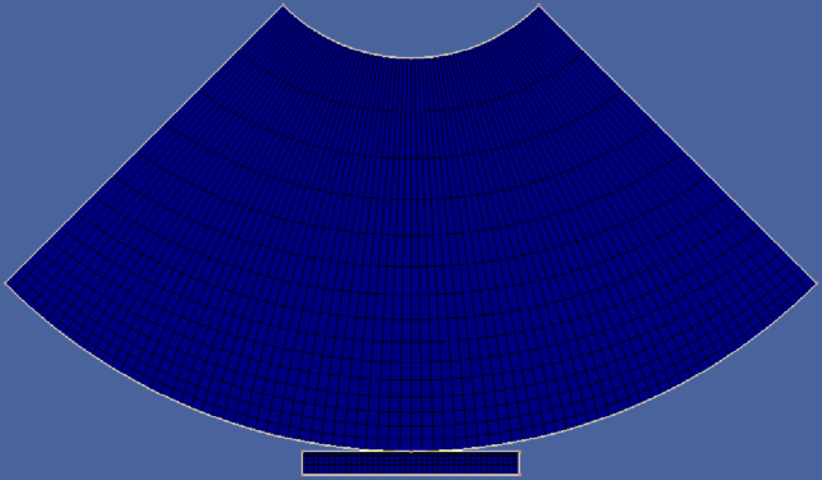
Machining using ALE

- A tool cuts and divides a piece of metal into two parts
- A guess of the final stationary shape of the chip is used as initial mesh.
- The final shape (chip width) is automatically computed by the ALE method
- The mesh is refined near the crack.
- The model could be highly improved with an appropriate fracture model.



Cold Rolling process using ALE formalism

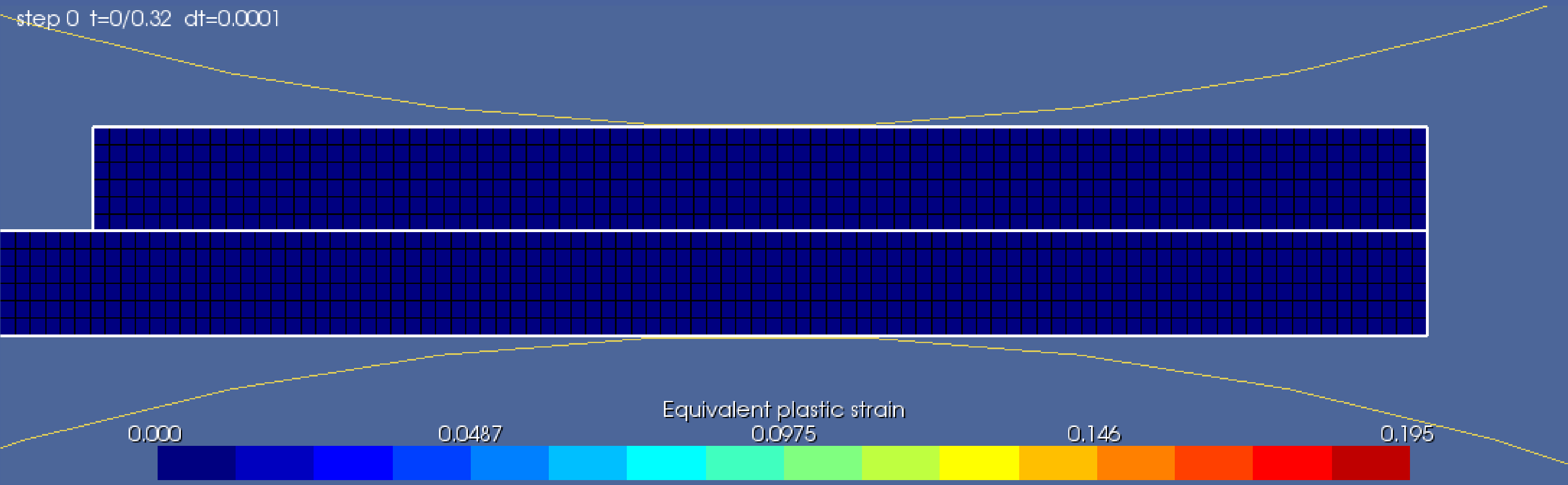




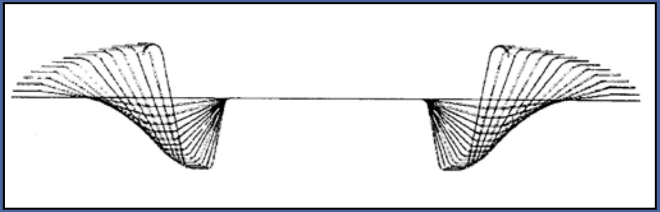
- Only the interesting part of the problem is meshed, thanks to the ALE formalism.
- The mesh is Eulerian in the rolling direction and Lagrangian in the transverse direction.
- The stationary state is reached by first clamping the sheet between the rolls and secondly making them rotate around their axis.
- The rolls deformation is taken into account and the sheet is thick.
- The free surface of the sheet in the outlet zone is automatically computed using spline remeshing.
- Eulerian convection of the Gauss points values is performed using a 1st order Finite Volume algorithm.

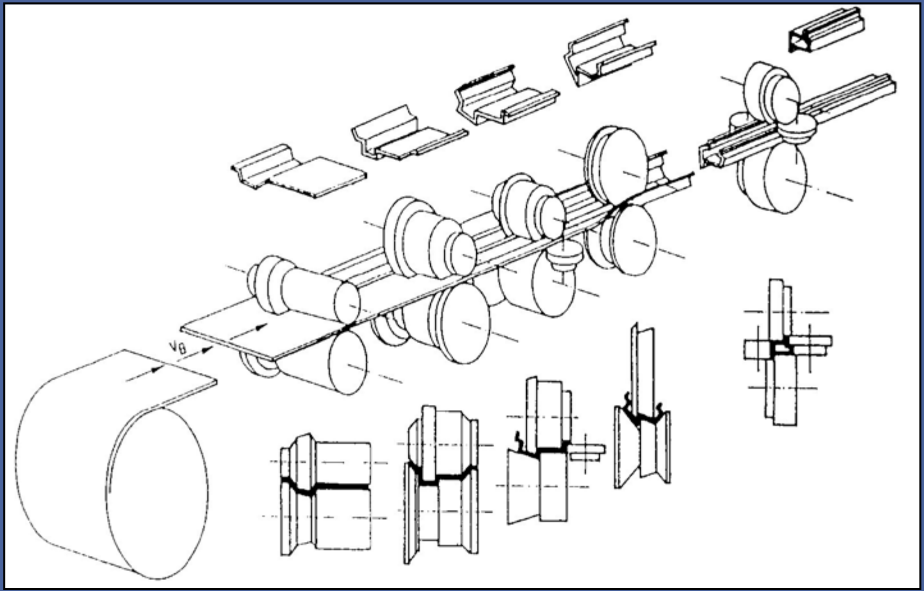
Cold Rolling process using ALE formalism

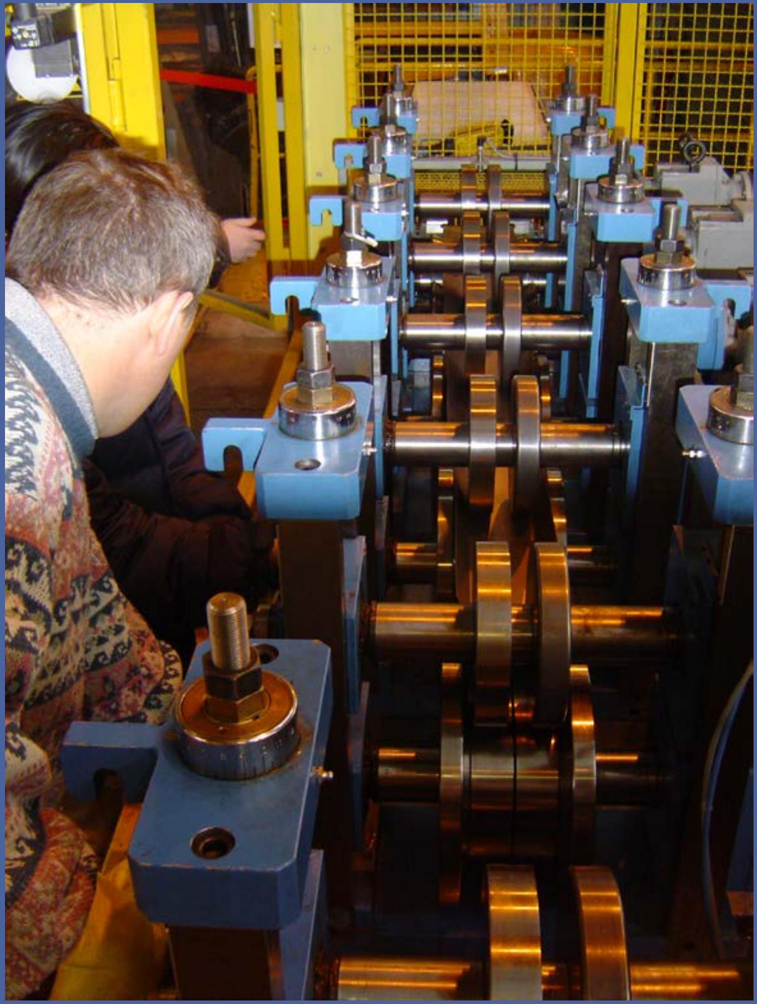
Comparison between ALE (above) and Lagrangian (below) formalisms



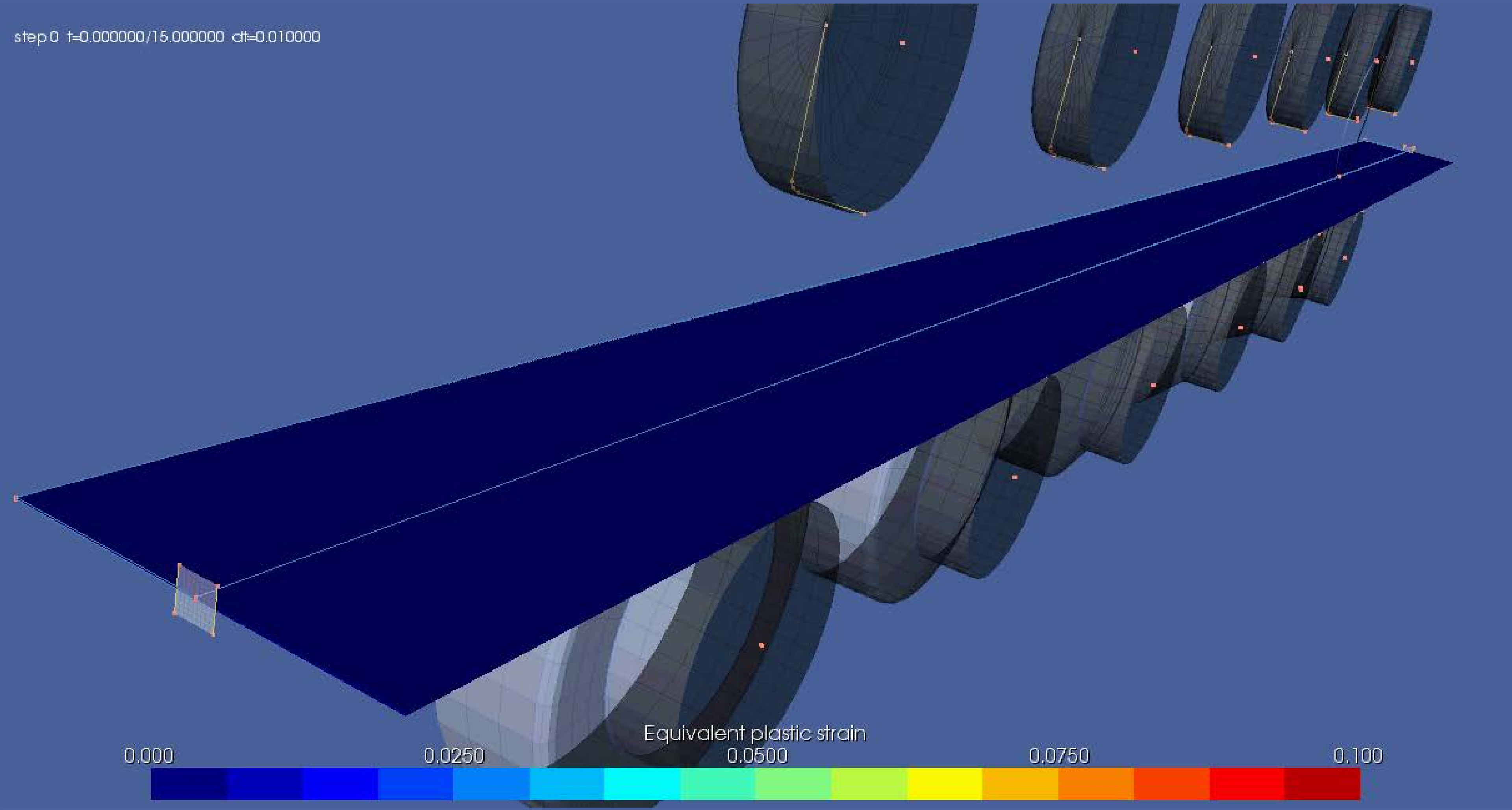
Roll forming







Roll forming – ALE simulation



Conclusion

The future

- Process chaining and optimization
- Material parameters identification
- Shells – higher order elements – enhanced triangles/tetrahedrons
- More efficient contact-search algorithms (deep drawing of car panels)
- High performance computing (parallelization) : SMP then clusters
- Remeshing algorithms
- Improving the modularity and the efficiency of each library
- …